Effects of processing temperature and optical anisotropy of a polymeric insulator on organic thin-film transistors

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Abstract

We investigate the effect of processing temperature of gate insulator and optical anisotropy on organic thin-film transistors (OTFTs). The insulator film which was processed lower temperature than solvent boiling temperature can lead more aligned pentacne molecules compare to higher processed insulator film. It finally gives rise to the big increase of carrier mobility in OTFTs, although there are little difference at the seriously affecting properties to device performance, for example roughness of gate insulator film.

1. Introduction

Organic thin-film transistors (OTFTs) have been studied in the last decade due to their large potentials to electronic applications such as electronic papers, various sensors [1-3]. Most of researches with high mobility on pentacene based OTFTs are using the SiO_2 as a gate insulator [4]. However, SiO_2 requires high temperature processing, high vacuum deposition processing, and has the limitation of use on flexible substrates. Therefore, OTFTs based on SiO_2 are not suitable for flexible devices which have become the core of modern trend as next generation display. To accomplish the flexible devices, organic insulator used solution processing such as spin coating is essential due to low temperature processing.

Moreover, there are many researches on the interface between organic gate insulator layer and semiconductor layer, because the interface phenomena such as roughness of gate insulator are deeply affect the device performance. However, in respect of using these organic materials, there are little studies on the relationship of solute and solvent, organic treatment condition such as temperatures. Moreover, the fundamental physics behind the surface induced molecular ordering and the resultant surface morphologies are not ascertained clearly.

In this work, we apply the photo-polymer poly(vinyl cinnamate) (PVCi) commonly used to align the liquid crystals by spin coating on our OTFTs as a gate insulators. Focusing on the processing conditions of solution processed polymeric insulator, PVCi, we find that the OTFTs based on lower processed PVCi film than solvent boiling temperature (T_b) can show the better device performance such as mobility due to the aligned PVCi layer. Furthermore, we verify the aligned pentacene molecules through measured optical anisotropy.

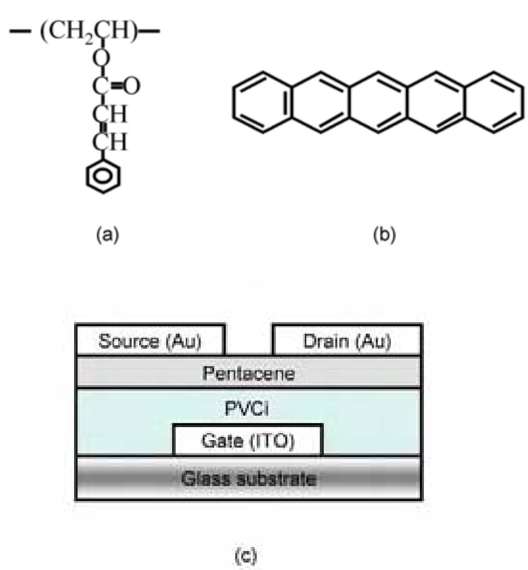

Figure 1. (a) is molecular structure of the PVCi as a gate insulator, (b) is molecular structure of the pentacene molecule as a semiconductor, and (c) is device structure of top contact organic thin-film transistors.

2. Experimnets

The device structure is shown in Fig. 1. Glass is used as a substrate, indium-tin-oxide (ITO) is used as a gate electrode. The ITO patterned glass was cleaned with acetone, iso-prophyl alcohol, methanol and de-ionized water on sequence. The PVCi, purchased from Aldrich, dissolved in a cyclopentanone of 10 wt.% was used as a insulator. The solvent T_b of cyclopentanone is 130 °C. We processed the organic insulator, PVCi film, at 60 °C (below T_b) and 180 °C (above T_b) for the enough time to completly remove the residual solvent, cyclopentanone. In order to generate the anisotropic anchoring force for the pentacene molecules, the linear polarized ultra violet light was exposed equally for 3 minutes after processing on the PVCi. We used a broadband UV source of a high pressure Hg lamp for photo-aligned the PVCi. The pentacene films without extra purifications were deposited as the semiconductor layer through a shadow mask onto PVCi polymeric insulator layer under about 10^{-6} Torr. The pentacene thickness was 60nm and evaporation rate was fixed 0.5 Å/sec. During the deposition, the sample substrates were held at room temperature. The Au was then thermally deposited through another shadow mask to make source and drain electrode under 10^{-6} Torr for OTFTs fabrication. The channel length and width are 50 µm , 1 mm, respectively. The current voltage characteristics and electrical properties of our OTFTs were measured by a HP4155A semiconductor parameter analyzer in the ambient pressure, room temperature. Atomic force microscopy (AFM) is carried out to figure out the surface morphologies of pentacene films deposited on the PVCi film. Moreover, photo elastic modulator (PEM) is used to measure the optical anisotropy of pentacene molecules.

3. Results and Discussion

By controlling processing temperature, we find that all of the RMS roughness values on PVCi film is not changed, 2.9 ± 0.5 Å. The relation of insulator roughness and semiconductor layer grain size were well known matters in OTFTs [5]. Generally, the rougher insulator film is, the smaller semiconductor grain size has. However, the pentacne grain size deposited on PVCi film is increased and grain boundary is decreased shown in Fig. 2 by lowering PVCi processing temperature.

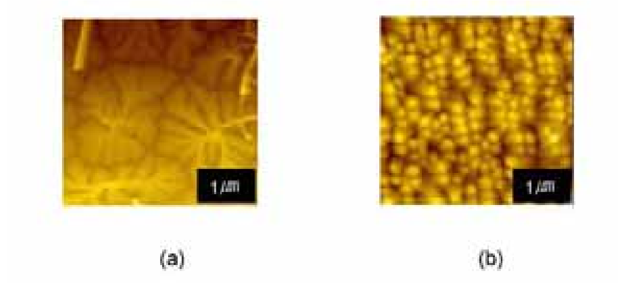

Figure 2. The AFM images of pentacene films which were depostied on PVCi film processed at (a) 60 °C and (b) 180 °C .

Furthermore, we study the optical anisotropy of PVCi film and pentacene film deposited on PVCi film by PEM method. The PEM method usually used to measure on optical anisotropy of the liquid crystal (LC), even the tiny optical anisotropy such as LC alignment layer. Considering that the pentacene molecule has a rod-shape like a LC molecule, it is expected that the structural ordering of the pentacene moleculs can be induced on an aligned layer of the liquid crystal molecules through anisotropic surface anchoring shown in Fig. 3 [6].

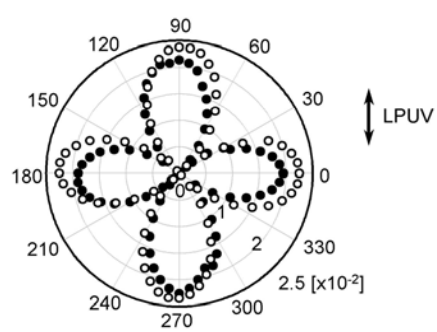

Figure 3. The optical anisotropy of the pentacene thin films (open circle) on a PVCi layer (closed circle) which was processed at 60 °C. The thickness of pentacene film and PVCi are 60 nm and 570 nm, respectively.

In fact, the grain size and the optical anisotropy are expected to be strongly correlated with each other. The optical anisotropy exists in such more ordered configuration of the rod-like pentacene molecules. Larger retardation value represents more ordered pentacene molecules shown in Fig. 3.

We make the OTFTs in proper form which was already shown in Fig. 1(c). The output characteristic curves are shown Fig. 4. The applied gate voltage range is from 0 V to –60 V with –10 V steps. The magnitude of drain current (I_D) is decreased by raising the insulator processing temperature from 60 °C to 180 °C. The carrier mobility was calculated from the following formula in the saturation region : [7]

$$I_D = \frac{W}{2L} C_i \mu (V_G - V_T)^2$$

where L and W are the channel length and width, respectively, C_i is PVCi capacitance per unit area, μ is the carrier mobility in saturation region, V_G is the gate voltage, and V_T is the threshold voltage.

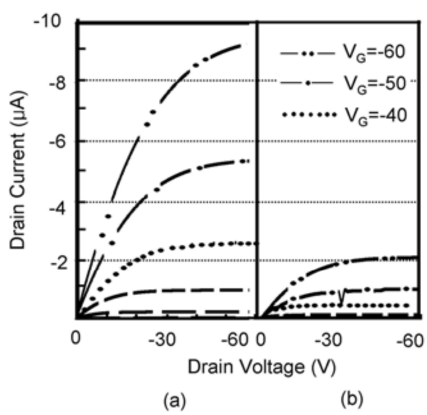

Figure 4. The output characteristics curves of OTFTs based on different temperature processed PVCi films, at (a) 60 °C and (b) 180 °C.

The saturation region mobility was decided at drain source voltage (V_{DS}) of –60 V. At a V_{DS} of –60V, the mobility of 60 °C, 180 °C processing temperature conditioned devices are 0.10 cm^2/Vs, 0.03 cm^2/Vs, respectively. The mobility of OTFTs on PVCi at 60 °C processing temperature is above three times larger than that of 180 °C processing temperature. All of the devices show the similar I_{ON}/I_{OFF} ratio : above 10^3. Table Ⅰ summarizes the electrical results of our OTFTs. It clearly shows that the device performance is decreasing by raising insulator processing temperature.

Table I. Summary of the electrical characteristics of our OTFTs.

Processing Temperature	Carrier Mobility μ (cm^2/Vs)	Threshold Voltage V_T (V)	I_{on}/I_{off}
60 ℃	0.10	-20	$\geq 10^3$
180 ℃	0.03	-21	

3. Conclusion

We report that the solvent processing temperature of organic insulator is critical to the performance of OTFTs. There are a large increase of pentacene grain size by lowering solvent processing temperature of insulator film, in spite of no difference on insulator surface roughness which strongly affect the pentacene grain size. We investigate the optical anisotropy of pentacene films. It coincides with the AFM images. Controlling processing temperature in organic insulator film is one of the important matter of fabricating improved performance OTFTs.

4. Acknowledgements

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5. References

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